DEVELOPMENT OF HIGH COTTON-CONTENT FIRE-RETARDANT FABRICS FOR NAVY PROTECTIVE CLOTHING

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George F. Ruppenicker

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U.S. Department of Agriculture
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Research was conducted to develop chambray, and 2/1-twill, work-uniform fabrics that could be adequately treated for fire retardancy and durable press, and still retain acceptable strength properties. Past attempts in combining the two finishes had resulted in a problem of substantial decreases in both the breaking and tearing strengths of 100% cotton fabrics. The problem was particularly acute in the filling direction. In an effort to overcome the problem, fabrics were designed and woven using 100% cotton ring-spun warps and cotton/nylon and cotton/polyester filament-core filling yarns. Fabrics containing various intimate blends of cotton and Kevlar staple in both warp and filling were also produced. The cotton/Kevlar blend provided the best approach to producing "combination fire-resistant and durable-press" shirting fabrics with acceptable tensile properties. Blend fabrics containing at least one-third Kevlar generally met the requirement of both breaking and tearing strengths. The fabrics produced with filament-core yarns, although they showed improved strength in the filling direction, had significant losses in the warp direction (due to 100% cotton warps) after durable-press finishing, indicating that it would be difficult to design a shirting fabric with this technique that would meet both strength and weight specifications.

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Development of High Cotton-Content Fire Retardant Fabrics for Navy Protective Clothing

INTRODUCTION

Research was conducted to develop shirting fabrics that could be treated with flame-retardant (FR), and combination flame-retardant and durable-press (FR + DP) finishes and still meet the required minimum strength specifications. The two fabrics selected for this work were a chambray with a maximum finished weight of 5.6 oz/sq yd, and a 2/1-left hand twill with a maximum weight of 6 oz/sq yd. In an effort to improve strength properties of the fabrics, the following two approaches were evaluated:

1. Use of high tenacity filament-reinforced cotton yarns (cotton/filament-core yarns) in the filling (the weaker) direction.

2. Use of cotton/aramid intimate blends in both warp and filling directions.

Carded cotton was used in the core and blend yarns for both fabrics. Experimental fabrics of approximately 21-inch width were woven on a narrow shuttle loom. They were desized, scoured, and then treated with FR and (FR +

DP) finishes. The fabrics were tested under standard conditions for their strength properties in the greige, scoured, FR, and (FR + DP) states. The testing of greige, scoured and FR-treated fabrics was done in the "machine state" (i.e., off the loom, or the tenter frame) and that of the (FR + DP)-treated fabrics was done after one laundering.

1. FABRICS WITH THE FILAMENT CORE-YARN IN THE FILLING

The "core-yarn-filling" fabrics were produced with the 25/1 core-yarn fillings containing 55d and 70d polyester cores and 40d and 70d nylon cores. Fabrics were also woven with the 22/1 filling yarns containing 100d nylon and 110d polyester cores. All the core fibers were of high tenacity. Strength properties of the core yarns and comparable 100% cotton yarns are given in Table I. Also included in the table are the ratios of the core fiber to the cotton wrapping fibers for each of the core yarns. The filament core content of the yarn ranged from a minimum of 19% to a maximum of 46% of the total yarn weight. All the core yarns were significantly stronger than comparable 100% cotton yarns.

The warp in the fabrics consisted of 100% cotton ring-spun yarns; 18/1 for the chambray and 22/1 for the twill fabrics. The work was originally started with rotor-spun (open-end) warp yarns, but the yarns were found to be considerably weaker than comparable ring-spun yarns. So, the use of rotor-spun yarns for the warps was abandoned in favor of the ring-spun yarns. Also, in the case of ring-spun yarns, the process of combing remained a viable option to improve yarn strength and quality, if necessary.

Preparation of all the fabrics for finishing included desizing and scouring. Since the warp yarns were slashed with polyvinyl alcohol, a simple boil-off was used for desizing. The scouring was done with a 0.7% caustic solution. The scoured fabrics were then treated for FR with an aqueous solution of tetrakishydroxymethyl phosphonium chloride-urea precondensate (THPC-urea),

the complete formula for which was:

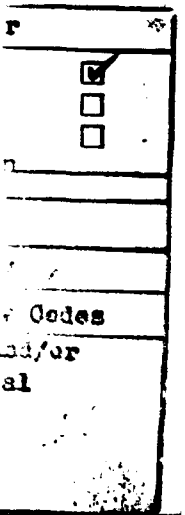
25.0%	THPC-urea (Retardol AC)
00.3%	Polyethylene softener
00.2%	Wetting agent
02.0%	Sodium acetate

The formulation represents the solids content of active agents in the pad bath. The pH of the solution was adjusted to about 4.50. The fabrics were first padded to a wet pick-up of 73%, dried at 185°F for 2 minutes, and then cured in an ammoniator. The cured fabrics were oxidized in a jig with a 0.8% aqueous solution of hydrogen peroxide, washed, and dried. The level of FR finish was about the same as that normally used for 100% cotton, since the overall manmade fiber content of the fabrics was relatively low. The manmade fibers (nylon and polyester) are combustible but unaffected by the finish.

Finally, the FR-treated fabrics were given a DP finish. The DP finish consisted of padding the fabrics with a 10% aqueous solution of dimethyloldihydroxyethyleneurea (DMDHEU) to a wet pick-up of about 73%. The complete formula was as follows:

10.0%	DMDHEU
03.0%	Magnesium Chloride catalyst
00.2%	Polyethylene softener

The pH of the solution was adjusted to about 4.0 with acetic acid. The fabrics were dried at 200°F for 2 minutes, and cured at 325°F for 3 minutes. This finishing treatment was somewhat more severe than that normally used for 100% cotton fabrics, because the presence of the FR finish has a tendency to block some of the reaction with cotton. The DP finish also reacts, to some extent, with the FR finish.



Chambray Fabrics

Thread counts and weights of the core-yarn chambray fabrics are given in Tables II and III. The fabrics were woven with nominal thread counts of 70 ends and 52 picks per inch and finished with thread counts of approximately 71 x 51. Fabric weights increased about 13% (from the desized and scoured state) after the FR finish and approximately 17% after the combination "FR + DP" finish. On the average, the thread-counts and weights of completely finished fabrics only slightly exceeded in the minimum requirements as outlined in the Military Specification MIL-C-24916, since the fabrics were purposely designed to be on the light side (weightwise) to accommodate the weight increase due to the special finishes.

Fire-resistance and durable-press properties of the core-yarn chambray fabrics are given in Table IV. As seen, all the fabrics, generally, had acceptable FR levels as determined by the char length test. Wrinkle recovery was on the low side, but it should be adequate for the type of fabric.

Grab breaking strengths of the core-yarn chambray fabrics are given in Table V. The warpwise breaking strengths of the fabrics in the greige and scoured states are too low to meet minimum specifications. This could be improved by using a slightly heavier warp yarn (i.e., 17/1) without exceeding the fabric weight limits. The warpwise breaking strengths of the FR-treated fabrics are marginally acceptable. It is not unusual for the FR-finished fabric to exhibit slightly increased strength, because the FR finish adds a polymer that does not cross link with cotton. On the other hand, the DP finishing decreased warpwise breaking strength by approximately one-third. However the fillingwise strength of all the core-yarn fabrics, except the one with the 40d nylon-reinforced yarn, had acceptable strength after the DP finishing. Based on these results, it, therefore, appears that it would be difficult to design a chambray fabric of 100% cotton warp yarns that would meet the strength specifications after DP finishing,

without reducing the level of the DP finish.

Elmendorf tearing strengths of the core-yarn chambray fabrics are given in Table VI. The tearing strength of all the fabrics, with the exception of the 100% cotton fabrics, was satisfactory in the greige and scoured states. After the FR finishing, which caused stiffening of the fabrics, the warpwise tearing strengths were only marginal, but the fillingwise strengths of most of the fabrics containing core-yarns were sufficient. However, after the DP finish the tearing strengths decreased to the extent that the fabrics would not be acceptable.

Twill Fabrics

Thread-counts and weights of the twill fabrics are given in Tables VII and VIII. The fabrics were woven with nominal thread counts of 94 ends and 50 picks per inch and had thread counts of approximately 100 x 50 after complete finishing. After the FR treatment, fabric weights increased an average of about 14% from the desized and scoured states, and after the combination FR + DP finish they increased a total of 17%. The thread-counts and weights of the desized/scoured and finished fabrics generally were within the range outlined in Military Specifications NCTRF/PD 4-90.

The fire-resistance and durable-press properties of the twill fabrics are given in Table IX. As with the chambray fabrics, all the treated twill fabrics had acceptable FR properties as determined by the char length test. The wrinkle recoveries were also about the same as for the chambray fabrics.

Grab breaking strengths of the twill fabrics are given in Table X. All the core-yarn twill fabrics, except for the one reinforced with 40d nylon, had acceptable breaking strengths in the greige, scoured, and FR-treated states. Fabrics with 100% cotton fillings did not meet the minimum grab breaking strength specification in the filling direction. DP finishing, as it did for the

chambray series, reduced the warpwise breaking strength of the fabrics by about one-third. However, most of the core-yarn-filling fabrics had acceptable strengths in the filling direction after DP finishing.

Elmendorf tearing strengths of the core-yarn twill fabrics are given in Table XI. All the core-yarn filling-fabrics had acceptable tearing strengths in both the warp and filling directions in the greige, scoured, and FR-treated states. After the DP finishing, however, the warpwise tearing strength was too low. Only those fabrics with yarns containing a 70d (or higher) filament reinforcement exceeded the strength requirements in the filling direction.

2. COTTON/KEVLAR INTIMATE BLEND FABRICS

Cotton/Kevlar intimate blend fabrics were produced at three blend levels: 80% cotton/20% Kevlar, 65% cotton/35% Kevlar; and 50% cotton/50% Kevlar. The same blend levels were used for both the chambray and twill fabrics. Strength properties of the ring-spun blend yarns and comparable 100% cotton yarns are given in Table XII. Blending only 20% Kevlar with cotton resulted in increases of over 40% in yarn strength. Yarns containing 50% Kevlar were more than twice as strong as comparable 100% cotton yarns. However, the blending of Kevlar with cotton reduces yarn elongation considerably.

Experimental yarns of 18/1 warp for the chambray, 22/1 warp for the twill, and 25/1 filling for both fabrics were woven into the chambray and twill constructions. The greige fabrics were desized and scoured with a 0.7% solution of caustic soda. The fabrics were then treated with an aqueous solution of tetrakishydroxymethyl phosphonium chloride-urea precondensate (THPC-urea). The complete formula was as follows:

20.0%	THPC-urea (Retardol AC)
00.3%	Polyethylene softener
00.2%	Wetting agent
02.0%	Sodium acetate

All formulations represent the solids content of active agents in the pad bath. The pH of the solution was adjusted to about 4.50. The fabrics were first padded to a wet pick-up of 75%, dried at 185°F for 2 minutes, and then cured in an ammoniator. The cured fabrics were oxidized in a jig with a 0.8% aqueous solution of hydrogen peroxide, washed and dried. The level of FR finish used was slightly lower than that normally used for 100% cotton because Kevlar is inherently fire-resistant.

Since Kevlar is sensitive to ultraviolet light, the fabrics, after the FR finish were treated with a photostabilizer and lightfastness improver (Cibafast N manufactured by Ciba-Gergy) developed primarily for Nylon. As far as is known, no such product is commercially available specifically for Kevlar. The fabrics were treated with a 5% aqueous solution (which is about twice the recommended level of finish for 100% nylon) of the commercial product (based on the weight of the nylon) on a jig for 20 minutes at 160 - 180°F, squeezed on a padder, and dried. Incidentally, an allowance was made for some of the finish to be absorbed by the cotton.

The cotton/Kevlar blend fabrics were finally given a DP finish, using the same procedures and treatment-levels as for the core-yarn fabrics.

Thread-counts and weights of the fabrics are given in Tables XIII an XIV. The chambray and twill fabrics were woven with nominal thread counts of 70 x 52 and 94 x 50, respectively. Fabric weights increased with the addition of the FR and DP finishes. Thread-counts and weights were generally within the range outlined in the military specifications.

Fire-resistance and durable-press properties of the cotton/Kevlar blend fabrics are compared with comparable 100% cotton fabric in Table XV. Although the 100% cotton fabric had a higher level of FR finish, the cotton/Kevlar blends generally had better flammability resistance. This is because of the inherent flammability-resistance of Kevlar. As with the core-yarn fabrics, the wrinkle recovery was on the low side, but should be adequate for the types of fabrics.

Grab breaking strengths of the blend fabrics are given in Table XVI. All the cotton/Kevlar blend fabrics had significantly higher breaking strengths than

the cotton fabric in the greige and all finishing stages. For example, both the chambray and twill, 50% cotton/50% Kevlar blend, fabrics had over twice the strength of the comparable all-cotton fabric after the FR + DP finish. In all cases, the blend fabrics exceeded specifications for breaking strength in the warp direction. The strengths in the filling direction after the FR + DP finish were marginal or too low for the lower blend levels, which, however, could be corrected with a slight adjustment in the filling thread count (picks per inch), without exceeding weight specifications.

Elmendorf tearing strengths of the cotton/Kevlar blend fabrics are given in Table XVII. Blending only 20% Kevlar with cotton resulted in substantial gains in tearing strength compared with the all-cotton fabric. All the fabrics, with the exception of the 80% cotton/20% Kevlar blend chambray with the FR + DP finish, had acceptable tearing strength after each stage in processing.

CONCLUSIONS

Blending cotton with Kevlar offers the best approach for producing flame-resistant shirting fabrics with durable-press features and acceptable strength properties. Blend fabrics containing at least one-third Kevlar generally met both the breaking and tearing strength requirements after the FR + DP finish and were of reasonably lightweight. It is possible that the fabric structures could be adjusted slightly to accommodate the 80% cotton/20% Kevlar blend. Concerns with the cotton/Kevlar blends, however, are the sensitivity of Kevlar to ultraviolet light, and the yellow color which could offer some dyeing problems.

Filament-core yarns in the filling direction provided an effective approach to improving fabric strength properties in that direction. However, the 100% cotton yarns in the warp degraded to the extent that it would be difficult to design a shirting fabric of this type that would meet strength specifications after DP finishing. One possible solution would be to substantially reduce the level of the DP finish. It should also be possible to design a filling core-yarn fabric with FR finish only, that would meet all strength specifications.

Table I. Properties of Core Yarns and Controls.

Yarn	% Core	Skein CSP[1/]	Single Strand Tenacity (g/tex)	Single Strand Elongation-at-Break (%)
25/1				
100 % Cotton	0	2128	13.5	6.1
55d Polyester	26	3477	19.8	7.8
70d Polyester	33	4181	23.1	10.2
40d Nylon	19	2375	13.9	6.3
70d Nylon	33	3991	23.3	16.6
22/1				
100d Nylon	41	5054	30.1	16.6
110d Polyester	46	5365	30.8	17.7
100% Cotton	0	2158	14.0	7.1

[1/] CSP = Breaking strength in lbs. X yarn No.

Table II. Thread Count of Chambray Filling Core-Yarn Fabrics.

Filling[1/]	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
25/1								
100% Cotton	70	53	74	50	72	50	71	50
55d Polyester	69	53	74	49	72	50	71	51
70d Polyester	69	52	74	52	72	50	71	51
40d Nylon	70	53	75	51	74	50	72	51
70d Nylon	71	53	76	51	73	50	72	51
22/1								
100d Nylon	70	51	76	49	72	49	72	51
110d Polyester	68	53	76	49	72	47	72	51
100% Cotton	71	52	75	48	73	47	71	51

[1/] All fabrics woven with 18/1, 100% cotton ring-spun warp.

Table III. Weight of Chambray Filling Core-Yarn Fabrics.

Fabric	Treatment (oz./sq. yd.)			
	Greige	Scoured	FR	FR + DP
25/1				
100 % Cotton	4.43	4.23	4.83	4.96
55d Polyester	4.42	4.25	4.80	4.97
70d Polyester	4.39	4.25	4.83	5.06
40d Nylon	4.43	4.32	4.86	4.99
70d Nylon	4.51	4.36	4.90	5.11
22/1				
100d Nylon	4.67	4.49	4.98	5.28
110d Polyester	4.56	4.31	4.90	5.17
100% Cotton	4.53	4.34	4.91	5.05

1/ All fabrics woven with 18/1, 100% cotton ring-spun warp.

Table IV. **Fire Resistance and Durable Press Properties of Chambray Filling Core-Yarn Fabrics.**

Filling[1/]	Treatment				
	FR		FR + DP		
	Char Length (in.)		Char Length (in.)		Wrinkle Recovery (°)
	W	F	W	F	W & F
25/1					
100% Cotton	2.50	2.21	2.30	2.17	229
55d Polyester	2.29	2.12	2.75	2.17	263
70d Polyester	1.96	1.50	3.08	2.59	264
40d Nylon	2.21	1.92	2.30	2.21	260
70d Nylon	2.54	2.33	2.83	2.33	261
22/1					
100d Nylon	2.83	2.96	3.25	3.04	261
110d Polyester	2.63	2.34	3.58	2.71	259
100% Cotton	2.13	2.46	2.17	2.46	269

[1/] All fabrics woven with 18/1, 100% cotton ring-spun warp.

Table V. Grab Breaking Strength of Chambray Filling Core-Yarn Fabrics.

Filling[1/]	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
25/1								
100% Cotton	69	38	73	35	81	43	53	27
55d Polyester	70	54	74	85	77	58	52	55
70d Polyester	68	67	75	60	82	69	54	68
40d Nylon	69	44	74	46	79	47	57	34
70d Nylon	71	69	74	63	78	70	55	72
22/1								
100d Nylon	70	91	78	93	83	102	53	95
110d Polyester	68	85	73	91	80	95	53	96
100% Cotton	68	45	73	46	74	50	46	28

[1/] All fabrics woven with 18/1, 100% cotton ring-spun warp.

Table VI. Elemendorf Tearing Strength of Chambray Filling Core-Yarn Fabrics.

Filling[1/]	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
25/1								
100% Cotton	5.8	2.6	5.5	2.5	3.9	2.0	2.6	1.1
55d Polyester	6.0	4.3	4.9	3.5	4.0	2.7	2.6	2.2
70d Polyester	6.4	4.8	4.9	3.4	3.9	3.1	2.6	2.6
40d Nylon	5.9	3.6	4.6	2.9	4.0	2.6	2.5	1.8
70d Nylon	5.8	4.1	4.3	3.0	3.9	3.0	2.6	2.7
22/1								
100d Nylon	5.6	8.1	4.4	5.2	3.6	5.1	2.6	4.5
110d Polyester	6.3	7.3	4.2	4.3	3.8	4.6	2.4	4.2
100% Cotton	5.8	3.2	4.1	2.7	4.0	2.5	2.2	1.0

[1/] All fabrics woven with 18/1, 100% cotton ring-spun warp.

Table VII. Thread Count of Twill Filling Core-Yarn Fabrics.

Filling[1/]	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
25/1								
100% Cotton	96	50	100	48	102	49	100	50
55d Polyester	94	49	101	48	103	52	100	50
70d Polyester	94	49	100	48	102	50	100	50
40d Nylon	96	50	100	48	106	50	100	50
70d Nylon	95	49	101	48	103	48	101	49
22/1								
100d Nylon	94	47	102	44	103	47	100	50
110d Polyester	94	47	100	45	103	46	99	50
100% Cotton	96	46	99	45	104	48	99	50

[1/] All fabrics woven with 22/1, 100% cotton ring-spun warp.

Table VIII. Weight of Twill Filling Core-Yarn Fabrics.

Fabric	Treatment (oz./sq. yd.)			
	Greige	Scoured	FR	FR + DP
25/1				
100 % Cotton	4.66	4.59	5.17	5.41
55d Polyester	4.60	4.51	5.22	5.34
70d Polyester	4.65	4.54	5.18	5.30
40d Nylon	4.72	4.58	5.30	5.32
70d Nylon	4.82	4.62	5.27	5.45
22/1				
100d Nylon	4.76	4.70	5.39	5.60
110d Polyester	4.68	4.60	5.31	5.47
100% Cotton	4.82	4.51	5.36	5.43

1/ All fabrics woven with 22/1, 100% cotton ring-spun warp.

Table IX. Fire Resistance and Durable Press Properties of Twill Filling Core-Yarn Fabrics.

Filling[1/]	Treatment				
	FR		FR + DP		
	Char Length (in.)		Char Length (in.)		Wrinkle Recovery (°)
	W	F	W	F	W & F
25/1					
100% Cotton	1.34	1.46	2.67	2.59	253
55d Polyester	2.71	2.17	3.13	3.92	264
70d Polyester	3.42	2.34	3.50	2.75	254
40d Nylon	2.92	2.91	2.87	2.83	252
70d Nylon	3.67	2.25	2.88	2.42	254
22/1					
100d Nylon	2.96	2.46	3.50	2.38	263
110d Polyester	3.09	2.25	3.62	2.63	258
100% Cotton	1.88	2.21	2.34	2.50	262

[1/] All fabrics woven with 22/1, 100% cotton ring-spun warp.

Table X. Grab Breaking Strength of Twill Filling Core-Yarn Fabrics.

Filling[1/]	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
25/1								
100% Cotton	93	37	97	40	100	36	66	25
55d Polyester	85	58	100	54	104	53	69	56
70d Polyester	85	65	102	61	99	63	70	71
40d Nylon	89	40	99	45	98	44	67	37
70d Nylon	85	68	101	62	103	75	72	73
22/1								
100d Nylon	83	88	101	88	100	106	71	96
110d Polyester	82	89	96	86	102	93	70	97
100% Cotton	87	46	103	43	94	43	71	26

[1/] All fabrics woven with 22/1, 100% cotton ring-spun warp.

Table XI. Elemendorf Tearing Strength of Twill Filling Core-Yarn Fabrics.

Filling[1/]	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
25/1								
100% Cotton	7.6	3.5	4.6	2.5	4.8	2.6	R[2/]	1.3
55d Polyester	8.4	6.6	5.1	4.1	4.9	3.7	3.1	2.6
70d Polyester	7.9	7.1	4.7	3.5	5.0	4.3	3.1	3.5
40d Nylon	7.7	5.3	4.5	3.5	4.9	3.9	3.1	2.3
70d Nylon	7.4	5.8	4.4	3.4	4.8	4.3	3.1	3.8
22/1								
100d Nylon	8.1	11.0	4.4	4.4	5.2	6.7	3.2	6.8
110d Polyester	8.7	11.2	4.6	4.8	5.2	6.3	3.3	5.9
100% Cotton	8.2	5.3	4.6	2.8	5.0	4.1	3.0	1.8

[1/] All fabrics woven with 22/1, 100% cotton ring-spun warp.

[2/] Reversion

Table XII. Properties of Cotton/Kevlar Blend Yarns

Yarn			Single Strand	
	Blend Ratio[1/]	Skein CSP[2/]	Tenacity (g/tex)	Elongation-at-Break (%)
18/1	100/0	2266	14.6	7.8
22/1	100/0	2158	14.0	7.1
25/1	100/0	2128	13.5	6.1
18/1	80/20	3363	20.2	5.6
22/1	80/20	3223	20.3	5.1
25/1	80/20	3140	19.0	4.8
18/1	65/35	4301	26.2	5.3
22/1	65/35	4133	26.0	4.9
25/1	65/35	4029	24.6	4.7
18/1	50/50	5270	32.7	5.4
22/1	50/50	5062	32.8	5.3
25/1	50/50	4997	30.8	4.6

[1/] Ratio of cotton to Kevlar

[2/] CSP = Breaking strength in lbs. X yarn no.

Table XIII. Thread Count of Cotton/Kevlar Blend Fabrics.

Fabric	Treatment							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
Chambray								
20% Kevlar	69	52	73	49	72	49	71	50
35% Kevlar	69	51	71	50	71	49	71	50
50% Kevlar	68	52	71	50	71	49	71	50
Twill								
20% Kevlar	94	49	100	48	101	48	98	48
35% Kevlar	94	49	98	48	101	48	97	48
50% Kevlar	94	49	98	48	100	49	98	49

Table XIV. Weight of Cotton/Kevlar Blend Fabrics.

Fabric	Treatment (oz./sq. yd.)			
	Greige	Scoured	FR	FR + DP
Chambray				
20% Kevlar	4.42	4.56	4.72	4.88
35% Kevlar	4.44	4.41	4.71	4.90
50% Kevlar	4.46	4.37	4.62	4.85
Twill				
20% Kevlar	4.74	4.69	5.30	5.21
35% Kevlar	4.73	4.77	5.25	5.32
50% Kevlar	4.63	4.71	5.16	5.16

Table XV. Fire Resistance and Durable Press Properties of Cotton/Kevlar Blend Fabrics and 100% Cotton controls.

Fabric	Treatment				
	FR		FR + DP		
	Char Length (in.)		Char Length (in.)		Wrinkle Recovery (o)
	W	F	W	F	W & F
Chambray					
100% Cotton	2.50	2.21	2.30	2.17	229
20% Kevlar	2.21	1.21	1.79	1.41	248
35% Kevlar	1.08	0.66	0.79	0.50	252
50% Kevlar	1.00	0.71	0.67	0.38	241
Twill					
100% Cotton	1.34	1.46	2.67	2.59	253
20% Kevlar	2.17	0.71	1.62	1.50	251
35% Kevlar	0.62	0.50	1.71	0.46	247
50% Kevlar	0.67	0.62	0.58	0.50	242

Table XVI. Grab Breaking Strength of Cotton/Kevlar Blend Fabrics and 100% Cotton controls.

Fabric	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
Chambray								
100% Cotton	69	38	73	35	81	43	53	27
20% Kevlar	105	53	92	45	104	52	81	39
35% Kevlar	125	63	118	56	117	61	99	49
50% Kevlar	151	67	132	67	129	65	116	56
Twill								
100% Cotton	93	37	97	40	100	36	66	25
20% Kevlar	123	52	116	45	122	46	87	34
35% Kevlar	152	64	140	57	137	53	114	45
50% Kevlar	176	69	163	58	155	57	134	52

Table XVII. Elemendorf Tearing Strength of Cotton/Kevlar Blend Fabrics and 100% Cotton controls.

Fabric	Treatment (lbs.)							
	Greige		Scoured		FR		FR + DP	
	W	F	W	F	W	F	W	F
Chambray								
100% Cotton	5.8	2.6	5.5	2.5	3.9	2.0	2.6	1.1
20% Kevlar	14.8	6.6	6.5	3.2	6.8	3.7	4.9	2.1
35% Kevlar	23.2	9.6	7.9	4.0	9.0	5.2	7.7	4.0
50% Kevlar	27.2	14.2	9.7	5.3	12.7	6.8	10.6	5.3
Twill								
100% Cotton	7.6	3.5	4.6	2.5	4.8	2.6	R[1/]	1.3
20% Kevlar	16.8	9.0	7.7	4.1	7.9	6.0	5.5	3.0
35% Kevlar	24.8	16.0	9.7	5.7	10.8	8.2	8.2	5.7
50% Kevlar	35.4	21.6	13.1	8.8	15.2	12.7	13.7	8.4

[1/] Reversion